氏　　　　　名	曲　　偉　峰
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学位授与の題目	Study of Effects of High Temperature Annealing on Electrical and Structural Properties of Poly-Si Films （ポリシリコン薄膜の構造と電気的特性に対する高温アニールの効果の研究）
論文審査委員	（主査）　鈴　木　正　國 （副査）　山　田　　実，長谷川　誠　一 佐々木　公　洋，北　川　章　夫

学位論文要旨

Abstract In this work, Effects of High Temperature Rapid Thermal Annealing (HT-RTA) on Electrical and Structural Properties of Poly-Si Films were studied using the gas flame heating system. The remarkable lateral grain growth of poly-Si films with maximum grain size of about 3.5μm has been obtained at annealing temperature about 1400℃ for 180s. It was found that secondary grain growth consists of two processes, the initial structural rearrangement of the grain boundaries and the subsequent grain growth. High doping efficiency was also attained by HT-RTA in phosphorus-doped poly-Si films. The improvement of electrical properties of phosphorus doped poly-Si films in association with their microscopic structure were investigated. From these results, the HT-RTA process by gas flames is effective.

Chapter 1 Introduction

Novel High-Temperature Rapid-Thermal-Annealing (HT-RTA) technology for large-area and high quality polycrystalline silicon (poly-Si) films are explored in this study. Conventional annealing methods are devised into three methods, furnace annealing, the excimer laser or lamp annealing and electron beam annealing, have been widely used. The furnace annealing is generally used in semiconductor industries. However, high temperature (＞1200℃) annealing is generally difficult for conventional furnaces. On the other hand, laser-beam and electron-beam annealing can easily attain high temperature. The annealing systems using laser-beam or electron-beam are expensive, and through-put of these annealing systems are rather low. In order to overcome these difficulties lateral sweep annealing using flat gas flame was proposed for HT-RTA. Experimental results obtained by lateral sweep HT-RTA using flat gas flame were not less than those by using laser equipment, so that high temperature annealing by gas flame is expected to be a promising method to produce high-quality poly-Si films.

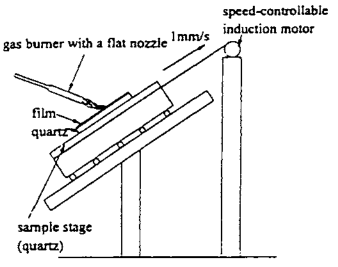

FIG. 1. A schematic diagram of the high-temperature annealing apparatus using flat gas flames.

Chapter 2 Gas flame annealing apparatus

We propose a novel lateral sweep annealing using flat gas flame for high temperature annealing method. Figure 1 shows a schematic diagram of the annealing apparatus using flat gas flame. In the diagram, the gas burner has a flat nozzle with a slit of 50×0.3 mm^2. The fuel gas used was so-called C6 gas (a mixture of hydrogen and lower hydrocarbon gases: 5000 kcal/m^3), and to attain high temperature, oxygen was mixed with the C6 gas. Figure 2 shows the temperature versus time curve where the heating rate is approximately 260 ℃/s around 1000℃. We here denote the highest temperature measured by the Pt-Pt/Rd thermocouple as the annealing temperature T_a. The temperature fluctuation was also measured to be ± 5℃. Temperature profiles as shown in Fig. 2 can be controlled by the flow rate of fuel gas and oxygen and the sweep speed of flat gas flame.

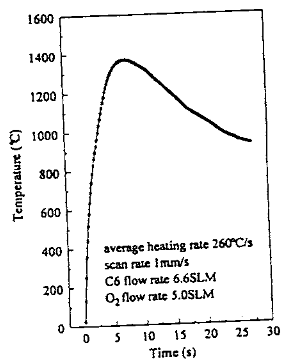

FIG. 2. Temperature vs time curve indicating a heating rate of about 260 °C/s.

Chapter 3 Effect of high temperature and short time annealing by gas flames

The effects of high temperature short time annealing (1s $<t<$ 10s) on the secondary grain growth in poly-Si films were studied using electron spin resonance and transmission electron microscopy. During the annealing processes, sample surfaces were laterally swept by the gas flame. The temperature range from 1150 to 1360℃ and annealing time was adjusted by the sample speed passing through the flat gas flame. The sample speed was fixed at

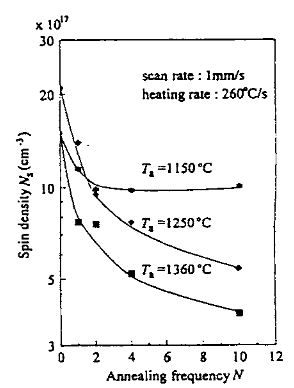

FIG. 3. Spin density N_s in *poly*-Si films as a function of annealing frequency N.

1 mm/s in this study. From the electron microscopy images, it was found that the secondary grain growth proceeded with increasing the number of annealing times annealing frequency and a grain size in the samples annealed at 1360℃ was more than 1μm whereas for the 1150℃-annealed samples the secondary grain growth was not significant.

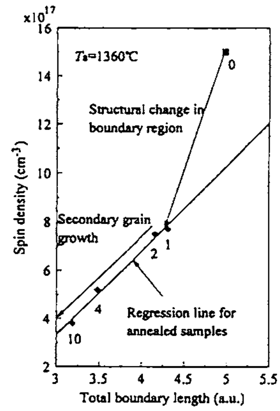

FIG. 4 Relation between the spin density N, and total length of grain boundaries L for 1360 °C-annealed samples.

Figure 3 shows variation of spin density with annealing frequency. For the samples annealed at 1360℃, spin densities determined from the resonance signals decreased from 1.5 x $10^{18}cm^{-3}$ to 3.8 x $10^{17}cm^{-3}$. It was concluded from the results of ESR and electron microscopy images that the secondary grain growth consists of two processes, as shown in Fig. 4, the initial structural rearrangement of the grain boundaries and the subsequent grain growth.

Chapter 4 Lateral grain growth in poly-Si films by gas flames high temperature annealing

Lateral grain growth in nondoped random orientation poly-Si films was studied using the HT-RTA in which samples at a stand still on the stage was exposed to flat gas flame for 120 sec. The remarkable lateral grain growth of poly-Si films (maximum grain size of about 3.5μm) with a strong (111) orientation has been obtained when annealed at 1400°C for about 180s. Figure 5 shows the transition of grain size distribution using annealing frequency N of gas flame high temperature. As a result of experimental study, we discovered that the result was about the same as that obtained by excimer laser annealing of 128 shots. It was clarified that the lateral grain growth phenomenon upon a gas flame annealing was strongly affected by both the microstructure and the orientation of the initial Si thin films.

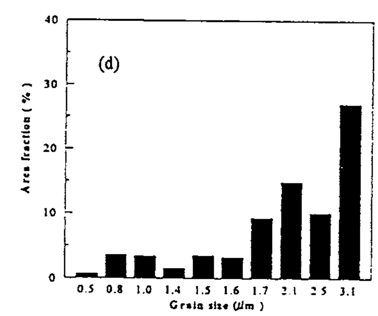

Fig. 5. Grain size distributions for the samplea annealed at 1400 C with N=6.

Chapter 5. Electrical and structural properties of rapid thermal annealed phosphorus-doped poly-Si films

Effects of HT-RTA using flat gas flame on the electrical properties of phosphorus-doped poly-Si films in association with their microscopic structure were studied. Samples with phosphorus concentration of 3.1×10^{17}~6.0×10^{20} cm^{-3} were prepared and annealed by HT-RTA ranging from 1150°C to 1350°C. During HT-RTA, sample surface was laterally swept by gas flames. Figure 6 shown the resistivity of the samples which decreased with increasing annealing temperature, and the lowest resistivity was 4.8×10^{-4} Ωcm for the sample doped with P of 6.0×10^{20} cm^{-3} when annealed at 1350°C. In Figure 7, Hall mobility, on the other hand, increased first and then decreased with increasing P concentration. The highest Hall mobility was 71.3 $cm^2/V \cdot s$ for the sample annealed at 1350°C of which P concentration was 3.5×10^{19} cm^{-3}. The results suggest that the grain boundary potential barriers for carriers decreased with increasing doping concentration and annealing temperature, and that the total area of grain boundaries in the films decreased with increasing annealing temperature because of secondary grain growth and the shrinkage of boundary width.

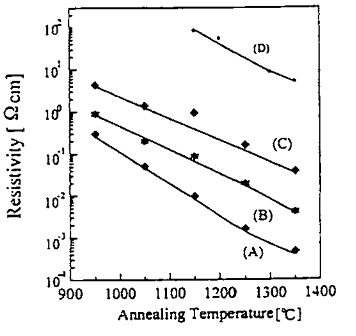

FIG. 6. Dependence of resistivity for poly-Si films on the annealing temperature.

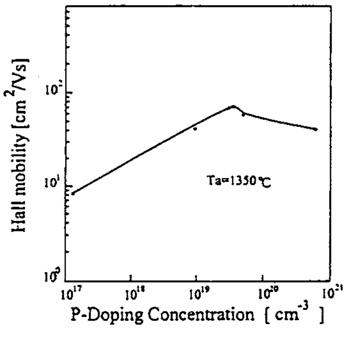

Fig. 7. Hall mobility of phosphorus-doped poly-Si film vs phosphorus concentration.

Chapter 6. Concluding summary

Effects of high temperature annealing on electrical and structural properties of poly-Si films were studied by flat gas flame. Lateral sweep is very effective for patent technological application..

(1) Remarkable secondary grain growth in poly-Si films was caused by flat gas flame lateral sweep annealing.

(2) Secondary grain growth process consists of initial structural rearrangement of the grain boundaries and the subsequent grain growth.

(3) The electrical and structural properties of phosphorus-doped poly-Si films were improved by HT-RTA.

(4) It is concluded that high-quality large-area poly-Si thin film can be prepared by flat gas flame lateral sweep annealing.

学位論文の審査結果の要旨

曲偉峰氏は，平板状ガス炎加熱ラテラルスキャンアニール法によりポリシリコン薄膜の高品質化の研究を行った。最初に，短時間高温アニールによる欠陥密度の減少の様子をESRにより評価し，結晶粒径の変化を透過電子顕微鏡観察により行った。その結果，高温アニールの初期段階では，まず無秩序な構造を持つ結晶粒界の構造緩和が起こりその厚みが減少することを見出した。それは急激なESRスピン密度の減少をもたらす。次いで，より表面自由エネルギーの低い結晶粒が隣接の自由エネルギーの高い結晶粒を蚕食するいわゆるSecondary Grain Growth (S.G.G.) が起こることを透過電子顕微鏡観察により確認した。

これらの結果をもとにして，不純物ドーピングによる伝導度の制御の実験を行った。4種類の異なるドーピング濃度を持つ資料について高温アニールを行い，SIMSによりドーパント濃度の分布を調べ，van der Paw法によりキャリア濃度とキャリアのモビリティーを測定し，高温アニールはドーパントの活性化率を劇的に向上させるとともにキャリアのモビリティを高める事を確認した。

以上の結果を，不純物偏析モデルや粒界トラップモデル等により検討し，平板状ガス炎加熱ラテラルスキャンアニール法はポリシリコン薄膜の高品質化に非常に有効である事を示した。よって博士の学位を授与する事が妥当であると結論された。